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Prediction of Growth after Thinning in Old-Field Slash Pine Plantations

by

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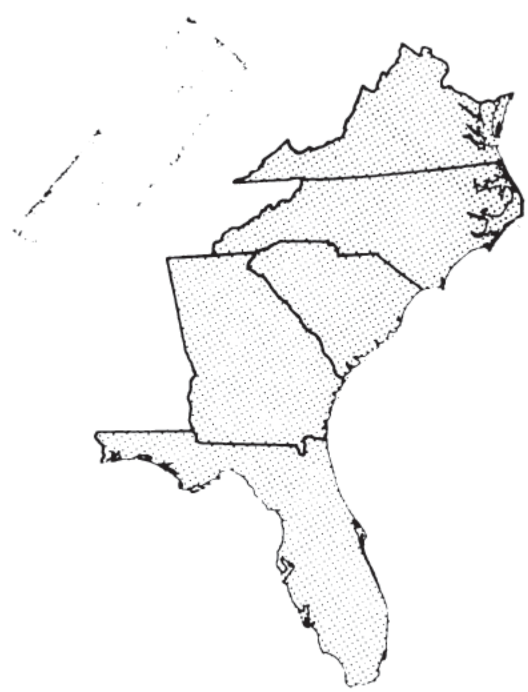

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ABSTRACT.—An algorithm is given for projecting stand structure in old-field slash pine plantations from current stand statistics that represent conditions after thinning from below, or without thinning. The algorithm is based on data collected from 212 quarter-acre plots in slash pine's range in Georgia, Florida, Alabama, and Mississippi. Plots represented ages from 9 to 32 years, basal areas from 25 to 150 square feet, and site indexes (at base age 25) of 47 to 80 feet. Projections for selected combinations of age, site index, and density are evaluated for total cubic-foot and board-foot volume production after thinning of 20, 25, 33, and 50 percent of volume and without thinning.

Keywords: *Pinus elliottii*, yield, mensuration.

Foresters have long recognized the mensurational and economic complexities involved in analyzing the effects of thinning. Valuable data on responses of thinned southern pine stands can be found in the reports of case histories and locally replicated studies (e.g., Dell and Collicott 1968; Keister, Crow and Burns 1968; Enghardt and Mann 1972), but no results from regional studies have been published.

This report presents initial results from a cooperative regional thinning study organized by the Southeastern Forest Experiment Station. Results include:

- A series of mathematical equations for predicting the subsequent development of thinned (or unthinned) old-field slash pine plantations.
- A comparison of predicted growth with actual growth for the plots that were used to develop the prediction equations.
- An analysis of the effects of thinning under a wide variety of situations.

A FORTRAN subroutine for computer implementation of the prediction equations is given in the Appendix.

THE DATA BASE

In 1958, the Southeastern Forest Experiment Station and a number of cooperators began a large slash pine plantation density study. The principal objective was to determine the effects of different residual stand densities upon the cubic-foot volume growth and total yield of planted slash pine over a broad range of ages and sites. Eighteen industry, government, and nonindustrial private landowners cooperated in providing old-field slash pine plantations for sampling. Sample plots were widely scattered over the Coastal Plain of southern Georgia and northern Florida, and along the Gulf Coast of Alabama and Mississippi. Slash pine plantations were selected for sampling to provide a broad representation of plantation ages and site indexes (based on a 25-year index age). Residual stand densities were in 25-square-foot basal-area classes with midpoints of 40, 65, 90, 115, 140, and 165.[1] Plantations were not chosen if they had a history of naval stores operations, frequent or damaging fires, or heavy rust infection; nor were those that had been interplanted or thinned. Plots were placed in portions of the plantation that had rather uniform planted pine stocking. No more than six merchantable-

[1] Ages at the beginning of the growth period ranged from 9 to 32 years. Minimum and maximum site-index values (calculated using Equation 3 in table 1) were 47 feet and 80 feet, respectively. Basal areas at the beginning of the growth period varied from 25 square feet per acre to 150 square feet per acre.

size wild pines or hardwoods were allowed. Greater numbers of unmerchantable wildlings were permitted.

In all, 296 monumented plots were established. Most were four-sided, as nearly square as plantation row alignment would allow, and close to one-quarter acre in size. Also included were some circular quarter-acre plots which were part of a similar study started in 1955.

The number of sample plots installed in each selected plantation depended on the highest density available. Except for those with a uniquely high basal area, plots in a plantation were randomly assigned for thinning to a basal-area class. Thinnings reduced basal area as nearly as practicable to the midpoint of the density class; plots with existing basal areas near the midpoint of their assigned class were left unthinned. Thinnings generally consisted of improvement cuts from below. Thus, most cut trees were in the lower merchantable and submerchantable diameter classes, but larger trees were taken if they were badly diseased or deformed. Due regard was given to the spacing of residuals to avoid "holes" in the residual stand.

Initial plot measurements included a 100-percent diameter tally of pine and hardwood trees more than 6 feet tall and a classification as to sawtimber or pulpwood. In each diameter class, the first and every following eighth tree were designated for measurements of total height, height to green crown, and crown class. Trees with a broken top, a low fork, or some other deformity that obviously affected height were passed over, and the next acceptable tree in the diameter class was measured.

The plots were remeasured in a similar way at the end of the growth period 5 years later. Trees in the original height sample were remeasured, and additional trees were measured to give at least the one-in-eight sample according to the new diameter distribution. Thinning treatments and remeasurements have continued beyond the first growth period, but the results are not reported here.

First and second measurements were compared for each plot and tree. Obvious errors were corrected, but plots for which data could not be reconciled were left out of the growth analysis. Of the original 296 plots installed, 212 were used in the present analysis.

THE STAND-STRUCTURE PROJECTION ALGORITHM

Analysis of the data base just described has produced a computerized algorithm for predicting the future stand structure of old-field slash pine plantations. To make predictions, the following information about the residual stand is necessary:

- Age of the stand.
- Site index (25-year index age).
- A current stand table that shows the number of trees per acre by 1-inch diameter class together with the average diameter and average height of the trees in each class.

Diameter distributions after thinning may be measured or they may be calculated by the method of Bennett and Clutter (1968) and Bennett (1970). When diameter distributions are calculated, diameter class midpoints will generally serve as the initial average diameters. When the stand table is based on field measurements, the average diameters can be calculated as mean d.b.h. values by diameter class.

The equations for the stand-structure projection algorithm are listed below:

$$N_2 = [N_1^{-0.870841} + 0.0000146437\,(A_2^{1.37454} - A_1^{1.37454})]^{[(-0.870841)^{-1}]} \tag{1}$$

$$\ln(B_2) = (A_1/A_2)^{0.659976}\ln(B_1) + 5.74478[1 - (A_1/A_2)^{0.659976}] \tag{2}$$

$$\ln(S) = 3.75044 + 1.4488e^{-9.26795/A}[\ln(H) + 17.6098/A - 4.45483] \tag{3}$$

$$\ln(H) = 0.69024e^{9.26795/A}[\ln(S) - 3.75044] - 17.60980/A + 4.45483 \tag{4}$$

$$n_{2i} = [n_{1i}p_i/(\sum_i n_{1i}p_i)]N_2 \tag{5}$$

where $\text{probit}(p_i) = 6.76748 + 1.00456 \ln(b_{1i}/\bar{b}_1)$ (*see* footnote 2)

$$d_{2i} = [\bar{b}_2 K (b_{1i}/\bar{b}_1)^U / 0.005454]^{0.5} \tag{6}$$

$$\text{where } K = N_2 / \sum_i n_{2i}(b_{1i}/\bar{b}_1)^U$$

$$\text{and} \quad U = (A_1/A_2)^{0.0578109}$$

$$h_{2i} = H_2 (h_{1i}/H_1)^{[(A_1/A_2)^{-0.224491}]} \tag{7}$$

Definitions for symbols in the equations are:

A_1 = plantation age at the beginning of the growth period (years)
A_2 = plantation age at the end of the growth period (years)
N_1 = number of surviving stems per acre at the beginning of the growth period
N_2 = number of surviving stems per acre at the end of the growth period
B_1 = basal area per acre at the beginning of the growth period (square feet)
B_2 = basal area per acre at the end of the growth period (square feet)
H_1 = average height of dominant and codominant trees at the beginning of the growth period (feet)
H_2 = average height of dominant and codominant trees at the end of the growth period (feet)
S = site index at index age of 25 years (feet)
n_{1i} = number of surviving stems per acre in diameter class "i" at the beginning of the growth period
n_{2i} = number of surviving stems per acre in diameter class "i" at the end of the growth period
b_{1i} = average basal area per tree for diameter class "i" at the beginning of the growth period (square feet)
$\bar{b}_1$ = average basal area per tree for the entire stand at the beginning of the growth period (square feet)
d_{1i} = average d.b.h. for diameter class "i" at the beginning of the growth period (inches)
d_{2i} = average d.b.h. for diameter class "i" at the end of the growth period (inches)
$\bar{b}_2$ = average basal area per tree for the entire stand at the end of the growth period (square feet)
h_{1i} = average height of trees in diameter class "i" at the beginning of the growth period (feet)
h_{2i} = average height of trees in diameter class "i" at the end of the growth period (feet)
e = 2.71828 . . ., the base of natural logarithms
ln denotes a natural logarithm
$\sum_i$ denotes a summation over all occupied diameter classes

The following operations are required to apply the equations:

1. Determine the appropriate values for A_1, A_2, N_1, B_1, H_1, and S. N_1 and B_1 can be calculated from the after-thinning stand table. If H_1 is known, S can be calculated from equation (3). If S is known, H_1 can be calculated by solving equation (4) with $A = A_1$.
2. Compute $\bar{b}_1 = B_1/N_1$ and the b_{1i} values.
3. Calculate N_2 and B_2 with equations (1) and (2), and compute $\bar{b}_2 = B_2/N_2$.
4. Compute H_2 by solving equation (4) with $A = A_2$.
5. Calculate the p_i value for each diameter class, and then solve equation (5) for each diameter class to give the n_{2i} values.
6. Solve equations (6) and (7) for each diameter class to give the d_{2i} and h_{2i} values.

These computations produce a stand table showing numbers of trees, average diameters, and average heights by diameter classes at the end of the projection period. The total number of trees per acre in the stand table will be N_2 as calculated from equation (1) in step 3. If basal area per acre is computed from n_{2i} and d_{2i} values, the result will be B_2 as calculated with equation (2) in step 3.

This projection algorithm differs from conventional stand table projection methods in that it does not move trees from one class to another. Instead, the class statistics change. For example, diameter class i begins the growth period containing n_{1i} trees, which are treated as all having

[2]The probit transformation is defined as follows:

$$\text{Probit}(x) = 5.0 + Z_x \qquad (0 \le x \le 1)$$

where Z_x is the value of the standard normal variable such that probability $(Z \le Z_x) = x$.

d.b.h. values equal to d_{1i} and total heights equal to h_{1i}. At the end of the growth period, n_{2i} of the original n_{1i} trees are still alive with d.b.h. values equal to d_{2i} and total heights equal to h_{2i}. This overall projection procedure is similar to the method developed by Clutter and Allison (1974) for *Pinus radiata* in New Zealand.

A COMPARISON OF OBSERVED AND PREDICTED VALUES

Data from the same 212 growth-period observations that were used to develop the prediction equations were analyzed with the stand structure projection algorithm to generate comparisons of observed growth statistics with corresponding predicted values. On each plot, the observed after-thinning diameter distribution and average heights, by d.b.h. class, were used as input to the algorithm. Predicted end-of-period statistics calculated by the algorithm were compared with corresponding end-of-period observed values.

A summary of these comparisons is shown in table 1. For each stand variable, the average of the observed values and the average of the values predicted by the model are shown together with

Table 1.—Comparison of observed and predicted values, per acre

Stand characteristic	Average observed value	Average predicted value	Percent of variation explained
ALL PLOTS (n = 212)			
Number of trees at age A_2	298.6	299.5	98.7
Basal area at age A_2 (ft^2)	100.4	100.5	96.7
Cubic-foot volume at age A_2	2,598	2,620	93.6
Board-foot volume at age A_2	1,010	1,031	94.0
Mortality during period (number of stems)	18.7	19.6	42.1
Basal-area growth during period (ft^2)	19.6	19.7	59.9
Cubic-foot growth during period	1,000	1,022	81.5
Board-foot growth during period	589	610	85.8
THINNED PLOTS (n = 153)			
Number of trees at age A_2	271.4	274.1*	98.8
Basal area at age A_2 (ft^2)	91.9	92.5	96.5
Cubic-foot volume at age A_2	2,359	2,398	93.0
Board-foot volume at age A_2	822	844	92.3
Mortality during period (number of stems)	17.9	20.7*	54.0
Basal-area growth during period (ft^2)	19.2	19.8	60.8
Cubic-foot growth during period	919	957	65.1
Board-foot growth during period	472	494	73.8
UNTHINNED PLOTS (n = 59)			
Number of trees at age A_2	369.2	365.2	98.0
Basal area at age A_2 (ft^2)	122.6	121.3	93.7
Cubic-foot volume at age A_2	3,217	3,195	91.6
Board-foot volume at age A_2	1,497	1,515	95.1
Mortality during period (number of stems)	20.7	16.7	17.6
Basal-area growth during period (ft^2)	20.8	19.4	56.9
Cubic-foot growth during period	1,210	1,188	90.3
Board-foot growth during period	894	912	91.7

All cubic-foot volume and growth figures are outside-bark merchantable volumes to a 4.0-inch (o.b.) top diameter and include all stems with d.b.h. greater than 4.5 inches. The volume table used was developed by Bennett and others (1959).

All board-foot volume and growth figures are International ¼-inch scale and are based on a volume equation developed by Bennett (1959).

*Average predicted value differs significantly at the 5-percent level from the corresponding average observed value.

the percent of variation explained by the model. For a given stand variable Y, the percent of variation explained was calculated as:

$$PVE = 100 \left\{ 1 - [\Sigma(Y_i - \hat{Y}_i)^2] / [\Sigma(Y_i - \bar{Y})^2] \right\}$$

where:

PVE = percent of variation explained,

Y_i = observed value of Y for observation i,

$\hat{Y}_i$ = predicted value of Y for observation i,

$\bar{Y}$ = $\Sigma Y_i/n$, and

the summations are made over the n observations involved.

These statistics are tabulated for all 212 plots, and for the 153 thinned plots and the 59 unthinned plots. Agreement between observed and predicted values is generally quite close. In two of the 24 comparisons that are tabulated, average observed values differ significantly from the average predicted values. However, in neither of these cases is the magnitude of the difference sufficiently large to be of practical concern. The percentages of variation explained by the projection equations indicate good performance in most prediction situations.

As is common, mortality is predicted with less precision than any of the other dependent variables considered. For the unthinned plots, only 17.6 percent of the variation in observed mortality is explained by the model. Because the comparable figure is 54.0 percent in thinned stands, much of the unexplained mortality variation in unthinned stands is probably occurring in trees that would have been removed if a thinning had been performed (i.e., small trees and diseased trees). The fact that the model explains 90.3 percent of the variation in cubic-foot growth variability while accounting for only 17.6 percent of the variation in mortality seems to confirm this conjecture.

EFFECTS OF THINNING

Calculations were performed to evaluate the effect of thinning on cubic-foot and board-foot production in a large number of representative thinning situations. Evaluations were carried out for various combinations of site index, thinning age, rotation age, stems per acre before thinning, and thinning intensity expressed as a percentage of merchantable cubic-foot volume removed. For each combination, stand structure at thinning age was calculated using techniques described by Bennett (1970) and Burkhart (1971). Yield without thinning was estimated with the stand structure projection algorithm to project this stand structure forward to rotation age. Comparable yield with thinning was obtained by removing sufficient stems from the diameter distribution at the age of thinning (beginning with the 5-inch class and moving upward) to provide the required percentage of volume removal. Projection of this residual stand to rotation age provided a yield estimate for the thinned stand at maturity, and a combination of this figure with the thinning yield gave an estimate of the total yield with thinning. The results of these computations are summarized in table 2.

Table 2 shows that thinning decreased cubic-foot volume production over the entire rotation in all of the cases considered, but the percentage of reduction was relatively small in many instances. Thinning generally increased board-foot volume production over the life of the stand and, in many cases, the percentage of increase was quite large.

Identification of situations where thinning is or is not advantageous requires economic analysis which is not attempted here. A growth-projection algorithm such as we present is required for such analysis, however. Because the algorithm that is presented here can be used for such purposes, a FORTRAN computer subroutine and related instructions for implementing the algorithm are given in the Appendix.

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APPENDIX

Computer Subroutine to Implement the Stand-Structure Projection Algorithm

The computer listing shown in this Appendix is a FORTRAN subroutine designed to carry out the computations in the algorithm that is presented in the text. Arguments that are provided to the subroutine are:

A1 = age of the stand at the beginning of the projection period.

A2 = age of the stand at the end of the projection period.

BA1 = basal area per acre at the beginning of the projection period.

SPA1 = number of stems per acre at the beginning of the projection period.

SI = site index (index age of 25 years).

F = a 20-element array containing initial numbers of stems per acre by d.b.h. classes, where F(I) is the initial number of stems per acre in diameter class I (I = 1, 2, . . ., 20).

D = a 20-element array containing initial average (midpoint) diameters by d.b.h. classes, where D(I) is the initial average diameter in diameter class I (I = 1, 2, . . ., 20).

H = a 20-element array containing initial average heights by d.b.h. classes, where H(I) is the initial average height for diameter class I (I = 1, 2, . . ., 20).

DL = a 20-element array containing initial lower limits for the d.b.h. classes, where DL(I) is the initial lower class limit for diameter class I (I = 1, 2, . . ., 20).

DU = a 20-element array containing initial upper limits for the d.b.h. classes, where DU(I) is the initial upper class limit for diameter class I (I = 1, 2, . . ., 20).

When the subroutine returns to the calling program, F, D, H, DL, and DU will contain values as of the end of the projection period. Other values returned are:

CFV = the per acre cubic-foot volume to a 4.0-inch top (o.b.) for all trees with d.b.h. 4.5 inches and larger.

BFV = the per acre board-foot volume (International ¼-inch scale) to a 6.0-inch top (o.b.) for all trees with d.b.h. 9.5 inches and larger.

This subroutine has been tested on IBM 370/158 equipment with a System/370 FORTRAN IV compiler. The subroutine makes use of the mathematical error function[3] (ERF), which is a FORTRAN-supplied procedure with System/370 FORTRAN. Users wishing to implement the subroutine with a FORTRAN compiler that lacks the ERF function will have to include their own function subprograms to evaluate the error function.

[3]The error function (ERF) is defined as

$$ERF(x) = (2/\sqrt{\pi}) \int_0^x e^{-u^2} du$$

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING

SITE INDEX: 50 THINNING AGE: 15 ROTATION AGE: 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING		YIELD WITH THINNING: TOTAL YIELD		YIELD WITHOUT THINNING		PERCENT CHANGE AS A RESULT OF THINNING	
			CU. FT.	BD. FT.	CU. FT.	BD. FT.	CU. FT.	BD. FT.	CU. FT.	BD. FT.
400	278	20	142	0	1952	601	2168	473	-10.0	27.0
400	261	25	177	0	1902	619	2168	473	-12.3	30.6
400	234	33	236	0	1815	652	2168	473	-16.3	37.9
400	179	50	354	0	1619	1848	2168	473	-25.3	290.7
500	367	20	140	0	1924	177	2154	158	-10.7	11.8
500	345	25	175	0	1869	205	2154	158	-13.2	29.2
500	319	33	234	0	1781	214	2154	158	-17.3	35.2
500	267	50	351	0	1581	1022	2154	158	-26.6	545.0
600	474	20	139	0	1900	56	2132	51	-10.9	10.1
600	443	25	174	0	1836	57	2132	51	-13.8	13.3
600	409	33	232	0	1739	67	2132	51	-18.4	32.9
600	356	50	348	0	1539	74	2132	51	-27.8	45.9
700	580	20	139	0	1890	20	2113	19	-11.0	6.8
700	550	25	173	0	1816	21	2113	19	-14.1	11.5
700	502	33	231	0	1706	22	2113	19	-19.3	16.6
700	453	50	347	0	1505	27	2113	19	-28.8	41.9
800	684	20	140	0	1872	11	2107	10	-11.2	7.8
800	655	25	175	0	1807	11	2107	10	-14.2	10.2
800	607	33	233	0	1695	11	2107	10	-19.6	14.7
800	550	50	349	0	1485	14	2107	10	-29.5	38.7

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 50 THINNING AGE: 15 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	YIELD WITH THINNING: REMOVED IN THINNING BD. FT.	YIELD WITH THINNING: TOTAL YIELD CU. FT.	YIELD WITH THINNING: TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	278	20	142	0	2539	3530	2822	2620	-10.0	34.7
400	261	25	177	0	2472	3695	2822	2620	-12.4	41.1
400	234	33	236	0	2354	3942	2822	2620	-16.6	50.5
400	179	50	354	0	2085	5023	2822	2620	-26.1	91.7
500	367	20	140	0	2491	2311	2795	1755	-10.9	31.7
500	345	25	175	0	2416	2507	2795	1755	-13.5	42.9
500	319	33	234	0	2295	2686	2795	1755	-17.9	53.1
500	267	50	351	0	2017	3401	2795	1755	-27.8	93.9
600	474	20	139	0	2447	1627	2757	1266	-11.2	28.5
600	443	25	174	0	2361	1756	2757	1266	-14.4	38.7
600	409	33	232	0	2227	1928	2757	1266	-19.2	52.3
600	358	50	348	0	1946	2414	2757	1266	-29.4	90.7
700	580	20	139	0	2411	1243	2726	991	-11.5	25.3
700	550	25	173	0	2324	1329	2726	991	-14.7	34.1
700	502	33	231	0	2171	1482	2726	991	-20.4	49.5
700	453	50	347	0	1889	1636	2726	991	-30.7	65.0
800	684	20	140	0	2390	1028	2709	838	-11.8	22.6
800	655	25	175	0	2302	1091	2709	838	-15.0	30.1
800	607	33	233	0	2145	1216	2709	838	-20.8	45.1
800	550	50	349	0	1851	1337	2709	838	-31.7	59.5

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 50 THINNING AGE: 20 ROTATION AGE: 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	BD. FT.	TOTAL YIELD CU. FT.	BD. FT.	YIELD WITHOUT THINNING CU. FT.	BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	BD. FT.
400	266	20	274	0	1993	381	2091	349	-4.7	9.2
400	242	25	343	0	1968	390	2091	349	-5.9	11.6
400	211	33	457	0	1927	409	2091	349	-7.9	17.2
400	160	50	686	0	1835	439	2091	349	-12.2	25.8
500	349	20	283	0	2058	102	2162	97	-4.8	5.1
500	324	25	354	0	2033	104	2162	97	-6.0	7.2
500	283	33	472	0	1988	107	2162	97	-8.0	10.7
500	224	50	709	0	1892	122	2162	97	-12.5	25.6
600	433	20	290	0	2101	16	2211	15	-5.0	2.2
600	408	25	362	0	2075	16	2211	15	-6.2	4.4
600	368	33	483	0	2029	17	2211	15	-8.2	8.5
600	294	50	724	0	1927	19	2211	15	-12.8	21.4
700	520	20	295	0	2134	1	2250	1	-5.1	0.1
700	495	25	369	0	2107	1	2250	1	-6.4	2.4
700	455	33	491	0	2059	1	2250	1	-8.5	7.0
700	375	50	737	0	1953	1	2250	1	-13.2	20.2
800	619	20	300	0	2164	0	2283	0	-5.2	0.0
800	585	25	374	0	2134	0	2283	0	-6.5	0.0
800	545	33	499	0	2085	0	2283	0	-8.7	0.0
800	466	50	749	0	1975	0	2283	0	-13.5	0.0

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 50 THINNING AGE: 20 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	YIELD WITH THINNING: REMOVED IN THINNING BD. FT.	YIELD WITH THINNING: TOTAL YIELD CU. FT.	YIELD WITH THINNING: TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	266	20	274	0	2575	2154	2743	1858	-6.1	15.9
400	242	25	343	0	2532	2247	2743	1858	-7.7	21.0
400	211	33	457	0	2458	2443	2743	1858	-10.4	31.5
400	160	50	686	0	2293	2994	2743	1858	-16.4	61.1
500	349	20	283	0	2648	1299	2827	1151	-6.3	12.8
500	324	25	354	0	2604	1358	2827	1151	-7.9	18.0
500	283	33	472	0	2525	1471	2827	1151	-10.7	27.7
500	224	50	709	0	2351	1847	2827	1151	-16.8	60.4
600	433	20	290	0	2695	817	2885	750	-6.6	9.0
600	408	25	362	0	2648	856	2885	750	-8.2	14.2
600	368	33	483	0	2566	933	2885	750	-11.1	24.4
600	294	50	724	0	2381	1166	2885	750	-17.5	55.5
700	520	20	295	0	2727	551	2929	521	-6.9	5.7
700	495	25	369	0	2679	577	2929	521	-8.5	10.7
700	455	33	491	0	2593	630	2929	521	-11.5	20.8
700	375	50	737	0	2399	782	2929	521	-18.1	50.1
800	619	20	300	0	2757	399	2967	381	-7.1	4.7
800	585	25	374	0	2703	411	2967	381	-8.9	8.1
800	545	33	499	0	2615	448	2967	381	-11.9	17.7
800	466	50	749	0	2414	553	2967	381	-18.6	45.3

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 60 THINNING AGE: 15 ROTATION AGE: 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING		YIELD WITH THINNING: TOTAL YIELD		YIELD WITHOUT THINNING		PERCENT CHANGE AS A RESULT OF THINNING	
			CU. FT.	BD. FT.	CU. FT.	BD. FT.	CU. FT.	BD. FT.	CU. FT.	BD. FT.
400	264	20	261	0	2952	3037	3169	2551	-6.8	19.0
400	239	25	327	0	2896	3171	3169	2551	-8.6	24.3
400	206	33	436	0	2798	3344	3169	2551	-11.7	31.1
400	155	50	653	0	2579	4135	3169	2551	-18.6	62.1
500	344	20	274	0	3062	2062	3293	1661	-7.0	24.1
500	316	25	343	0	3003	2121	3293	1661	-8.8	27.7
500	277	33	457	0	2899	2246	3293	1661	-12.0	35.2
500	215	50	685	0	2667	2809	3293	1661	-19.0	69.1
600	425	20	285	0	3150	1403	3395	1152	-7.2	21.8
600	400	25	357	0	3088	1491	3395	1152	-9.0	29.4
600	356	33	476	0	2979	1583	3395	1152	-12.3	37.4
600	280	50	713	0	2731	1780	3395	1152	-19.6	54.5
700	509	20	296	0	3229	1027	3490	866	-7.5	18.6
700	464	25	370	0	3165	1091	3490	866	-9.3	25.9
700	441	33	494	0	3050	1202	3490	866	-12.6	38.8
700	356	50	740	0	2788	1340	3490	866	-20.1	54.7
800	602	20	308	0	3312	822	3586	707	-7.7	16.2
800	570	25	384	0	3242	868	3586	707	-9.6	22.7
800	527	33	513	0	3123	963	3586	707	-12.9	36.2
800	442	50	769	0	2850	1088	3586	707	-20.5	53.8

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 60 THINNING AGE: 15 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING SQ. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD SQ. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING SQ. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING SQ. FT.
400	264	20	261	0	3680	7303	3949	5887	-6.8	24.0
400	239	25	327	0	3608	7776	3949	5887	-6.6	32.1
400	206	33	436	0	3481	8233	3949	5887	-11.8	39.8
400	155	50	653	0	3192	8207	3949	5887	-19.2	39.4
500	344	20	274	0	3795	5701	4084	4604	-7.1	23.8
500	318	25	343	0	3720	6063	4084	4604	-8.9	31.7
500	277	33	457	0	3555	6788	4084	4604	-12.2	47.5
500	215	50	685	0	3276	7610	4084	4604	-19.8	65.3
600	425	20	235	0	3884	4604	4194	3762	-7.4	22.4
600	400	25	357	0	3804	4904	4194	3762	-9.3	30.4
600	356	33	476	0	3662	5499	4194	3762	-12.7	46.2
600	280	50	713	0	3331	6825	4194	3762	-20.6	81.4
700	509	20	296	0	3963	3893	4294	3239	-7.7	20.2
700	484	25	370	0	3879	4149	4294	3239	-9.7	28.1
700	441	33	494	0	3729	4657	4294	3239	-13.2	43.8
700	356	50	740	0	3378	6136	4294	3239	-21.3	89.5
800	602	20	308	0	4047	3466	4397	2932	-8.0	18.2
800	570	25	384	0	3956	3681	4397	2932	-10.0	25.5
800	527	33	513	0	3798	4127	4397	2932	-13.6	40.7
800	442	50	769	0	3430	5410	4397	2932	-22.0	84.5

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 60 THINNING AGE: 20 ROTATION AGE: 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	YIELD WITH THINNING: REMOVED IN THINNING BD. FT.	YIELD WITH THINNING: TOTAL YIELD CU. FT.	YIELD WITH THINNING: TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	255	20	458	0	3097	2400	3200	2167	-3.2	10.8
400	234	25	573	0	3070	2461	3200	2167	-4.1	13.6
400	198	33	763	0	3022	2572	3200	2167	-5.6	18.7
400	143	50	1145	0	2914	2871	3200	2167	-8.9	32.5
500	323	20	493	0	3314	1458	3422	1370	-3.2	6.4
500	297	25	616	0	3286	1490	3422	1370	-4.0	8.8
500	260	33	821	0	3237	1552	3422	1370	-5.4	13.3
500	188	50	1232	0	3124	1694	3422	1370	-8.7	23.7
600	404	20	522	0	3499	902	3611	884	-3.1	2.0
600	368	25	653	0	3470	908	3611	884	-3.9	2.7
600	324	33	870	0	3419	938	3611	884	-5.3	6.2
600	246	50	1305	0	3300	1029	3611	884	-8.6	16.4
700	437	20	549	0	3665	588	3782	597	-3.1	-1.6
700	450	25	686	0	3635	590	3782	597	-3.9	-1.2
700	390	33	914	0	3581	593	3782	597	-5.3	-0.6
700	311	50	1371	0	3456	665	3782	597	-8.6	11.3
800	571	20	573	0	3818	405	3941	423	-3.1	-4.4
800	533	25	716	0	3787	407	3941	423	-3.9	-3.9
800	470	33	955	0	3731	409	3941	423	-5.3	-3.3
800	379	50	1433	0	3600	455	3941	423	-8.6	7.6

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 60 THINNING AGE: 20 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING		YIELD WITH THINNING: TOTAL YIELD		YIELD WITHOUT THINNING		PERCENT CHANGE AS A RESULT OF THINNING	
			CU. FT.	BD. FT.	CU. FT.	BD. FT.	CU. FT.	BD. FT.	CU. FT.	BD. FT.
400	255	20	458	0	3825	6043	3991	5359	-4.2	12.8
400	234	25	573	0	3780	6256	3991	5359	-5.3	16.7
400	196	33	763	0	3700	6663	3991	5359	-7.3	24.3
400	143	50	1145	0	3510	6572	3991	5359	-12.1	22.6
500	323	20	493	0	4069	4579	4242	2760	-4.1	65.9
500	297	25	616	0	4022	4741	4242	2760	-5.2	71.8
500	260	33	821	0	3938	5063	4242	2760	-7.2	83.5
500	188	50	1232	0	3742	5718	4242	2760	-11.8	107.2
600	404	20	522	0	4275	3522	4457	3295	-4.1	6.9
600	368	25	653	0	4227	3613	4457	3295	-5.2	9.7
600	324	33	870	0	4139	3852	4457	3295	-7.1	16.9
600	246	50	1305	0	3933	4562	4457	3295	-11.8	38.5
700	487	20	549	0	4459	1345	4649	2708	-4.1	-50.3
700	450	25	686	0	4408	1369	4649	2708	-5.2	-49.5
700	390	33	914	0	4316	2999	4649	2708	-7.2	10.8
700	311	50	1371	0	4099	3630	4649	2708	-11.8	34.1
800	571	20	573	0	4627	947	4828	2315	-4.2	-59.1
800	533	25	716	0	4574	963	4828	2315	-5.3	-58.4
800	470	33	955	0	4478	994	4828	2315	-7.3	-57.1
800	379	50	1433	0	4250	2994	4828	2315	-12.0	29.3

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 70   THINNING AGE: 15   ROTATION AGE: 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	YIELD WITH THINNING: REMOVED IN THINNING BD. FT.	YIELD WITH THINNING: TOTAL YIELD CU. FT.	YIELD WITH THINNING: TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	254	20	412	0	4057	6915	4267	5671	-4.9	21.9
400	234	25	515	0	3969	7293	4267	5671	-6.3	28.6
400	200	33	686	0	3896	7781	4267	5671	-8.7	37.2
400	141	50	1029	0	3654	8010	4267	5671	-14.4	41.2
500	326	20	446	0	4321	5287	4540	4368	-4.8	21.0
500	294	25	558	0	4261	5582	4540	4368	-6.1	27.8
500	258	33	743	0	4153	6158	4540	4368	-8.5	41.0
500	187	50	1115	0	3901	7316	4540	4368	-14.1	67.5
600	405	20	477	0	4565	4153	4783	3494	-4.8	18.9
600	370	25	596	0	4493	4374	4783	3494	-6.1	25.7
600	319	33	795	0	4380	4814	4783	3494	-8.4	37.8
600	245	50	1193	0	4115	6002	4783	3494	-14.0	71.8
700	435	20	506	0	4772	3401	5011	2929	-4.8	16.1
700	449	25	632	0	4707	3577	5011	2929	-6.1	22.1
700	389	33	844	0	4590	3917	5011	2929	-8.4	33.7
700	306	50	1266	0	4310	5010	5011	2929	-14.0	71.0
800	567	20	536	0	4984	2919	5234	2580	-4.8	13.1
800	530	25	670	0	4916	3067	5234	2580	-6.1	18.9
800	469	33	893	0	4793	3356	5234	2580	-8.4	30.1
800	372	50	1339	0	4498	4278	5234	2580	-14.1	65.8

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 70 THINNING AGE: 15 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	YIELD WITH THINNING: REMOVED IN THINNING BD. FT.	YIELD WITH THINNING: TOTAL YIELD CU. FT.	YIELD WITH THINNING: TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	254	20	412	0	4899	12289	5149	9528	-4.8	29.0
400	234	25	515	0	4827	12501	5149	9528	-6.2	31.2
400	200	33	686	0	4698	12726	5149	9528	-8.8	33.6
400	141	50	1029	0	4388	12099	5149	9528	-14.8	27.0
500	326	20	446	0	5185	8919	5444	7376	-4.8	20.9
500	294	25	558	0	5112	9216	5444	7376	-6.1	24.9
500	258	33	743	0	4976	11509	5444	7376	-8.6	56.0
500	167	50	1115	0	4653	11830	5444	7376	-14.5	60.4
600	405	20	477	0	5435	7532	5706	6201	-4.8	21.5
600	370	25	596	0	5359	7772	5706	6201	-6.1	25.3
600	319	33	795	0	5219	8223	5706	6201	-8.5	32.6
600	245	50	1193	0	4877	10944	5706	6201	-14.5	76.5
700	485	20	506	0	5667	6548	5952	5382	-4.8	21.7
700	449	25	633	0	5586	6746	5952	5382	-6.1	25.3
700	389	33	844	0	5440	7126	5952	5382	-8.6	32.4
700	306	50	1266	0	5078	10260	5952	5382	-14.7	90.6
800	567	20	536	0	5893	5886	6193	4841	-4.9	21.6
800	530	25	670	0	5808	6055	6193	4841	-6.2	25.1
800	469	33	893	0	5652	6380	6193	4841	-8.7	31.8
800	372	50	1339	0	5271	9766	6193	4841	-14.9	101.8

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 70 THINNING AGE: 20 ROTATION AGE: 25

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	YIELD WITH THINNING: REMOVED IN THINNING BD. FT.	YIELD WITH THINNING: TOTAL YIELD CU. FT.	YIELD WITH THINNING: TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	252	20	684	0	4405	6328	4506	5782	-2.3	9.4
400	227	25	855	0	4377	6474	4506	5782	-2.9	12.0
400	195	33	1140	0	4325	6741	4506	5782	-4.0	16.6
400	135	50	1710	0	4203	7046	4506	5782	-6.7	21.9
500	319	20	753	0	4810	4881	4912	4526	-2.1	7.8
500	290	25	941	0	4781	4977	4912	4526	-2.7	10.0
500	245	33	1255	0	4729	5158	4912	4526	-3.7	14.0
500	176	50	1883	0	4603	5650	4912	4526	-6.3	24.8
600	385	20	815	0	5173	3744	5276	3581	-2.0	4.6
600	355	25	1018	0	5144	3806	5276	3581	-2.5	6.3
600	304	33	1358	0	5091	3912	5276	3581	-3.5	9.2
600	222	50	2037	0	4961	4234	5276	3581	-6.0	18.2
700	456	20	871	0	5509	2906	5613	2899	-1.9	0.2
700	420	25	1089	0	5480	2939	5613	2899	-2.4	1.4
700	367	33	1452	0	5425	3008	5613	2899	-3.4	3.7
700	269	50	2179	0	5292	3181	5613	2899	-5.7	9.7
800	536	20	925	0	5878	2334	5934	2416	-1.8	-3.4
800	487	25	1157	0	5798	2318	5934	2416	-2.3	-4.1
800	432	33	1542	0	5742	2367	5934	2416	-3.2	-2.1
800	322	50	2313	0	5605	2453	5934	2416	-5.5	1.5

Continued

TABLE 2.–PER ACRE YIELD ESTIMATES FOR OLD-FIELD SLASH PINE PLANTATIONS WITH AND WITHOUT THINNING–CONTINUED

SITE INDEX: 70 THINNING AGE: 20 ROTATION AGE: 30

STEMS/ACRE BEFORE THINNING	STEMS/ACRE AFTER THINNING	PERCENT CU. FT. VOL. REMOVED	YIELD WITH THINNING: REMOVED IN THINNING CU. FT.	REMOVED IN THINNING BD. FT.	TOTAL YIELD CU. FT.	TOTAL YIELD BD. FT.	YIELD WITHOUT THINNING CU. FT.	YIELD WITHOUT THINNING BD. FT.	PERCENT CHANGE AS A RESULT OF THINNING CU. FT.	PERCENT CHANGE AS A RESULT OF THINNING BD. FT.
400	252	20	684	0	5271	10310	5425	9130	-2.8	12.9
400	227	25	855	0	5226	12065	5425	9130	-3.7	32.2
400	195	33	1140	0	5141	12019	5425	9130	-5.2	31.6
400	135	50	1710	0	4934	11214	5425	9130	-9.0	22.8
500	319	20	753	0	5712	8585	5866	7514	-2.6	14.2
500	290	25	941	0	5667	8746	5866	7514	-3.4	16.4
500	245	33	1255	0	5582	9049	5866	7514	-4.8	20.4
500	176	50	1883	0	5370	10715	5866	7514	-8.5	42.6
600	385	20	815	0	6108	6585	6262	6193	-2.5	6.3
600	355	25	1018	0	6061	7263	6262	6193	-3.2	17.3
600	304	33	1358	0	5976	7507	6262	6193	-4.6	21.2
600	222	50	2037	0	5758	9760	6262	6193	-8.1	57.6
700	456	20	871	0	6473	5474	6629	5166	-2.4	6.0
700	420	25	1089	0	6426	5570	6629	5166	-3.1	7.8
700	367	33	1452	0	6337	5751	6629	5166	-4.4	11.3
700	269	50	2179	0	6115	6802	6629	5166	-7.8	31.7
800	536	20	925	0	6818	4638	6977	4389	-2.3	5.7
800	487	25	1157	0	6771	4714	6977	4389	-3.0	7.4
800	432	33	1542	0	6679	4863	6977	4389	-4.3	10.8
800	322	50	2313	0	6450	5776	6977	4389	-7.5	31.6